The production of poultry in integrated aquaculture-agriculture systems

Part I: The integration of Peking and Muscovy ducks with vegetable production using nutrient-enriched water from intensive fish production systems during the winter period of March to September 1996

JF Prinsloo*, HJ Schoonbee and J Theron
Aquaculture Research Unit, University of the North, Private Bag X1106, Sovenga 0727, South Africa

Abstract

An investigation was made into the growth and production of Peking and Muscovy ducks on ponds using nutrient-enriched water from a water-recirculating intensive fish production system. The same water which received additional nutrients during a duck feeding programme was then used to irrigate selected vegetable crops. The production potential of Peking and Muscovy ducks was evaluated and the yields of different vegetable crops were compared with each other as well as with yields obtained during standard production practices. The application of this type of integrated aquaculture-agriculture system in rural areas as part of family-/community-based food production schemes is discussed.

Introduction

Integrated aquaculture-agriculture production systems have largely been developed in south-east Asian countries where they are at present well established as an important source of essential plant and animal protein (Pullen and Shehadeh, 1980; Hopkins and Cruz, 1982; Edwards and Pullen, 1990). In Africa, this type of food production system is still poorly developed (Pullen and Prein, 1995) and where in use, appears to be largely based on the integration of fish farming with rice (Diallo, 1992; Noble and Costa-Pierce, 1992). Commercially orientated integrated aquaculture-agriculture systems in South Africa since 1987 were investigated (Prinsloo and Schoonbee, 1987) when intensive studies were made into the feasibility of a duck-fish-vegetable integrated aquaculture-agriculture system for developing areas. This approach to food production is not only of particular importance to South Africa in view of the general scarcity of water resources (Department of Water Affairs and Forestry, 1997) but also because of its potential to combat the widespread problem of malnutrition which prevails in our rural populations (Tichelaar et al., 1995). The production of animal protein can do much to alleviate this situation in these areas (Steyn et al., 1995). It also serves as a good example of the possible approach towards the conservation, reuse and efficient management of our scarce water resources.

The present paper can be seen as a continuation of the developmental research originally done by Prinsloo and Schoonbee (1987) on integrated aquaculture-agriculture systems and of which this paper constitutes the first in a series on the establishment of farming- and community-based poultry-fish-vegetable farming systems aimed at sustainable food production in Southern Africa. Future papers will mainly deal with summer and winter production studies using laying hens and the grow-out of broiler chickens integrated with the propagation of fish and vegetable crops.

Materials and methods

Production layout

Five 30 m^3 earthen ponds, sealed with a 400 μ plastic material, were used in the investigation. Duck sheds of a simple, inexpensive construction and insulated with plastic material, were erected over the ponds. The floors of the duck sheds were covered with welded mesh to allow duck faeces and wasted food to fall directly into the pond water below. During day-time, ducks were allowed to enter the ponds.

Nutrient-enriched water from a water recirculating intensive fish production unit (Prinsloo et al., 1999a, b), was used to fill the duck ponds prior to stocking.

Aeration was applied to each pond by means of perforated plastic pipes connected to a low-pressure Elector side channel blower unit, model SE2-1057.

Water chemistry

Chemical parameters of the duck pond water were analysed according to *Standard Methods* (1995). Water temperature (°C) were measured using Thies hydro-thermographs. Dissolved oxygen concentrations (mg·ℓ^{-1}) of the wastewater were determined using an Oxy 92 oxygen meter. pH values were determined with a portable Hanna 8244 pH meter. The electrical conductivity (μS·cm^{-1}) was recorded with a Hanna HI 8633 conductivity meter. Ammonia (NH_3- mg·ℓ^{-1}), nitrite (NO_2- mg·ℓ^{-1}), nitrate (NO_3- mg·ℓ^{-1}), orthophosphate (PO_4- mg·ℓ^{-1}), as well as

---

* To whom all correspondence should be addressed.
☎ (015) 268-2294; fax(015)268-2294; e-mail koosp@unin.unorth.ac.za
Received 18 June 1998; accepted in revised form 12 October 1998.

turbidity (NTU) were all determined using a Hach spectrophotometer. Magnesium ($CaCO_3$- mg·ℓ^{-1}), calcium ($CaCO_3$- mg·ℓ^{-1}) and total hardness ($CaCO_3$-mg·ℓ^{-1}) were titrimetically determined. Mean values, as well as ranges for each parameter, were determined and tabulated.

Ducks used in the experiment

Ducks used in the investigation were obtained from Duckco Processing and Foods, a commercial producer at Kroondal, North-West Province. Specially formulated duck feed was obtained from a commercial producer. The starter diet consisted of a 22% protein mash whilst the finisher ration had a protein content of 18%.

Peking ducks

Three successive batches of 55 Peking ducks (11 per pond) were used in three growth cycles during the investigation lasting for 49 d (Cycle 2) or 55 d (Cycles 1 and 3). In the latter case (Cycles 1 and 3), day-old ducklings were used, whilst in Cycle 2 the ducklings available were already 5 d old. In Cycle 1, which took place during the warmer months of the investigation (February-March), ducklings were initially kept indoors for two weeks before being released onto the outdoor ponds. During Cycles 2 and 3 (May-June and July-August), which largely coincided with winter, ducklings were kept indoors for three weeks before being released onto the ponds. The difference in the growth periods of ducks on the ponds between Cycle 2 and Cycles 1 and 3, was one week as a result of the initial age difference.

Indoor feeding of ducklings was respectively done *ad lib* for two weeks (Cycle 1) and for three weeks (Cycles 2 and 3). Outdoor feeding was adjusted and varied between 15% (initially) and 10% (later) based on body mass with a final adjustment to 5% during the last week of the duck grow-out period. This final adjustment was necessary to slow down the rapid mass increase of the ducks which negatively affected their normal mobility on land.

Muscovy ducks

The feeding experiment for the Muscovy ducks lasted for 71 d between March and May, i.e. autumn to early winter. Muscovy ducks were found to be much slower growers than the Peking ducks. Consequently, they were kept indoors for almost four weeks and then released onto the ponds for another 42 d.

The Muscovy duck feeding programme largely corresponded with that of the Peking ducks. Feeding was, however, erratic and calculations had to be made on feed that was not consumed during certain days. Because of this and other inherent factors pertaining to their behaviour, the Muscovy ducks did not grow as well as the Peking ducks.

Vegetable production

Planting of cabbage, spinach and beetroot, took place on 30 March 1996. Carrots were sowed on 15 March 1996. Flood irrigation of the nutrient-rich water siphoned from the duck ponds was applied once a week to all four vegetable crops.

Fifteen plots for cabbage and ten each for carrots, beetroot and spinach, measuring 8 m^2 each, were used for the vegetable production. The sizes of the plots were deliberately kept as small units in view of the eventual evaluation of this type of approach i.e. towards the establishment of family/community food production units.

A standard fertilising programme was applied to the soil prior to planting of the vegetable crops. The fertiliser 2:3:2(30) was bandplaced at a concentration of 300 kg·ha^{-1} for carrots, beetroot and spinach. In the case of cabbage, the concentration was increased to 350 kg·ha^{-1}. A second application, 14 d after transplant, consisted of 250 kg·ha^{-1} 1:0:1(47) for carrots and beetroot, 150 kg·ha^{-1} LAN for spinach and 250 kg·ha^{-1} of a mixture of 50/50 LAN and 1:0:1(36) for cabbage. A third application consisting of the same fertilisers as used during the second application was provided approximately three to six weeks after planting of the different crops.

Harvesting of the different crops was as follows: Cabbage was harvested three months after planting. Spinach was cropped over a period of two to five months following planting. Beetroot and carrots, respectively, were cropped two and a half to three and a half, and four and a half to five and a half, months after planting. All crops were, as far as possible, completely harvested and excess leaves of cabbage, carrots and beetroot removed before weighing. At the end of the production season calculations were then made on the total production of each crop, expressed as kg produced per 1 000 m^2 plot.

Results

Water chemistry

Results on the water quality conditions of the Peking and Muscovy duck growth ponds before and during the period on the ponds are summarised in Tables 1 to 4.

The effect of the fish in the intensive fish production unit on the different physical and chemical properties of the water in the ponds is noticeable in all four tables. Initial variability in the different physical and chemical properties in some ponds, which can be mainly ascribed to phytoplankton growths, can clearly be seen in the dissolved oxygen concentrations as well as in turbidity values of Cycle 1 (Peking duck ponds) and Cycle 4 (Muscovy duck ponds) (Tables 1 and 4). In both cases, results were considerably higher than in the ponds used in Cycles 2 and 3 for the Peking ducks (Tables 2 and 3).

In ponds of Cycles 1 and 4, the oxygen concentration remained fairly high during the first four weeks after introduction of the ducks. Thereafter a significant decline in dissolved oxygen followed during Week 6 (Cycle 1) and Weeks 6 and 7 (Cycle 4). Oxygen concentrations in the Cycle 2 and 3 ponds were generally lower and resulted in a much more gradual decline over the period of investigation.

The effect of algal blooms on the water quality of the duck ponds of Cycle 4 is also reflected by a high pH which prevailed before the introduction of the ducks (Table 4). The pH of the water in ponds during all four cycles largely remained variable but alkaline. Values declined below 7 towards the end of the production cycle in all four cases.

There was a general increase of dissolved solids over time as reflected by the conductivity in all four cycles with values exceeding 200 µS·cm^{-1} in Cycles 2 and 3 during the latter stages of the investigation. In Cycles 1 (Peking ducks) and 4 (Muscovy ducks) the conductivity of the water remained generally lower with peak values of 162 and 174 µS·cm^{-1} at the end of the investigation.

Ammonia values in these two ponds were considerably lower than in ponds of Cycles 2 and 3. This particularly applied to the

TABLE 1
CHANGES IN WATER QUALITY CONDITIONS IN THE PEKING DUCKS GROW-OUT PONDS OVER A PERIOD OF SIX WEEKS (FEBRUARY-MARCH 1996: CYCLE 1). MEAN VALUES IN EACH CASE FOR FIVE SETS OF PONDS (MIN-MAX VALUES IN BRACKETS).

Analysis	N	Consecutive weeks (February-March 1996)						
		Before introduction	1	2	3	4	5	6
Dissolved oxygen, $mg \cdot \ell^{-1}$	5	10.68 (9.3-11.9)	12.9 (11.9-14.1)	18.3 (14.2-22.4)	14.3 (13.3-15.6)	13.1 (11.9-14.3)	9.9 (7.3-12.6)	4.4 (3.1-5.0)
pH	5	7.9-8.9	7.72-9.21	7.50-7.83	7.73-9.18	8.99-9.82	7.53-9.66	6.84-6.97
Conductivity $\mu S \cdot cm^{-1}$	5	94.4 (84.0-100.0)	125.2 (111.0-139.0)	123.4 (106.0-144.0)	123.0 (98.0-133.0)	133.2 (111.0-148.0)	149.6 (119.0-180.0)	162.2 (138.0-179.0)
Ammonia (NH_3), $mg \cdot \ell^{-1}$	5	0.33 (0.18-0.46)	0.61 (0.43-0.78)	0.90 (0.70-1.34)	0.96 (0.87-1.15)	1.03 (0.52-1.45)	1.56 (0.66-2.98)	1.89 (0.73-3.17)
Nitrite (NO_2), $mg \cdot \ell^{-1}$	5	0.007 (tr-0.013)	0.010 (tr-0.023)	0.009 (tr-0.040)	0.003 (tr-0.007)	0.002 (tr-0.069)	0.170 (0.092-0.218)	0.186 (0.013-0.789)
Nitrate (NO_3), $mg \cdot \ell^{-1}$	5	3.24 (tr-4.8)	6.26 (4.4-7.5)	8.54 (5.3-12.8)	3.52 (3.1-4.0)	12.32 (4.0-21.6)	6.96 (6.2-8.4)	7.58 (4.4-10.6)
Orthophosphate (PO_4), $mg \cdot \ell^{-1}$	5	3.77 (3.35-4.14)	5.81 (5.02-6.44)	9.05 (7.77-9.95)	7.36 (4.03-9.49)	7.19 (4.03-9.46)	8.11 (4.46-11.25)	12.57 (10.76-17.05)
Alkalinity as $CaCO_3$, $mg \cdot \ell^{-1}$	5	21.2 (16.0-28.0)	25.8 (21.0-30.0)	29.2 (22.0-38.0)	42.8 (39.0-46.0)	45.6 (34.0-55.0)	46.4 (30.0-55.0)	60.2 (48.0-80.0)
Ca hardness as $CaCO_3$, $mg \cdot \ell^{-1}$	5	21.4 (18.0-26.0)	25.4 (21.0-35.0)	23.8 (19.0-29.0)	32.8 (25.0-37.0)	33.0 (29.0-40.0)	36.6 (32.0-40.0)	46.6 (39.0-57.0)
Mg hardness as $MgCO_3$, $mg \cdot \ell^{-1}$	5	4.8 (3.0-7.0)	8.0 (5.0-12.0)	11.4 (5.0-16.0)	4.8 (1.0-9.0)	12.75 (5.0-23.0)	10.8 (4.0-24.0)	8.2 (5.4-10.6)
Total hardness as $CaCO_3$, $mg \cdot \ell^{-1}$	5	26.2 (22.0-33.0)	33.4 (26.0-47.0)	35.2 (29.0-43.0)	37.5 (30.0-45.0)	43.4 (30.0-53.0)	47.4 (39.0-62.0)	128.6 110.0-146.0)
Turbidity FTU	5	21.4 (10.0-32.0)	36.8 (17.0-59.0)	51.0 (30.0-75.0)	80.8 (56.0-114.0)	127.0 (78.0-143.0)	95.0 (66.0-130.0)	57.8 (40.0-76.0)

TABLE 2
CHANGES IN WATER QUALITY CONDITIONS IN THE PEKING DUCKS GROW-OUT PONDS OVER A PERIOD OF FIVE WEEKS (MAY-JUNE 1996 - CYCLE 2). MEAN VALUES IN EACH CASE FOR FIVE SETS OF PONDS (MIN-MAX VALUES IN BRACKETS).

Analysis	**N**	**Consecutive weeks (May - June 1996)**					
		Before introduction	**1**	**2**	**3**	**4**	**5**
Dissolved oxygen, $mg \cdot \ell^{-1}$	5	3.3	7.98 (7.5-8.4)	8.28 (7.6-8.6)	5.58 (4.4-7.2)	5.56 (4.0-6.9)	4.96 (1.7-6.0)
pH	5	6.81	7.18-7.42	7.19-7.29	7.12-7.28	7.11-7.25	6.95-7.26
Conductivity $\mu S \cdot cm^{-1}$	5	141	173.4 (163.0-194.0)	199.6 (168.0-238.0)	254.2 (186.0-310.0)	232.4 (196.0-262.0)	262.0 (210.0-308.0)
Ammonia (NH_3), $mg \cdot \ell^{-1}$	5	2.84	4.24 (2.61-7.14)	7.50 (5.37-10.86)	13.26 (8.72-19.15)	11.46 (7.93-12.93)	13.66 (10.0-16.2)
Nitrite (NO_2), $mg \cdot \ell^{-1}$	5	0.142	0.072 (0.317-1.254)	0.673 (0.310-1.132)	0.411 (0.185-0.472)	0.348 (0.195-0.554)	0.251 (0.122-0.403)
Nitrate (NO_3), $mg \cdot \ell^{-1}$	5	5.7	9.5 (7.9-10.6)	9.9 (8.4-11.4)	9.1 (6.6-11.4)	8.3 (5.3-11.4)	6.9 (5.7-8.8)
Orthophosphate (PO_4), $mg \cdot \ell^{-1}$	5	11.29	15.0 (13.6-16.8)	15.3 (10.5-18.6)	19.1 (11.7-21.8)	19.7 (15.0-21.9)	25.8 (17.4-31.0)
Alkalinity as $CaCO_3$, $mg \cdot \ell^{-1}$	5	38.0	50.2 (44.0-58.0)	58.2 (42.0-79.0)	-	75.8 (59.0-84.0)	88.4 (81.0-99.0)
Ca hardness as $CaCO_3$, $mg \cdot \ell^{-1}$	5	34.0	41.8 (38.0-44.0)	41.4 (34.0-51.0)	-	55.2 (48.0-69.0)	66.8 (47.0-92.0)
Mg hardness as $MgCO_3$, $mg \cdot \ell^{-1}$	5	12.0	12.8 (8.0-15.0)	17.0 (14.0-22.0)	-	22.6 (11.0-30.0)	19.6 (11.0-23.0)
Total hardness as $CaCO_3$, $mg \cdot \ell^{-1}$	5	46.0	54.6 (46.0-58.0)	58.4 (50.0-66.0)	-	77.8 (61.0-86.0)	78.4 (59.0-90.0)
Turbidity FTU	5	9.0	51.4 (38.0-68.0)	38.2 (20.0-50.0)	77.0 (45.0-110.0)	71.8 (48.0-113.0)	65.2 (46.0-109.0)

TABLE 3
CHANGES IN WATER QUALITY CONDITIONS IN THE PEKING DUCKS GROW-OUT PONDS OVER A PERIOD OF FIVE WEEKS (JULY-AUGUST 1996 - CYCLE 3). MEAN VALUES IN EACH CASE FOR FIVE SETS OF PONDS (MIN-MAX VALUES IN BRACKETS).

Analysis	**N**	**Consecutive weeks (July - August 1996)**					
		Before introduction	**1**	**2**	**3**	**4**	**5**
Dissolved oxygen, mg·ℓ^{-1}	5	3.4	7.5 (6.7-8.1)	7.7 (7.1-8.9)	5.1 (3.5-7.4)	5.3 (1.8-7.1)	4.8 (3.6-6.1)
pH	5	6.76	7.45-7.67	6.99-7.40	7.06-7.33	7.15-7.46	6.53-6.98
Conductivity µS·cm^{-1}	5	171.0	192.2 (166.0-224.0)	207.0 (191.0-245.0)	212.0 (182.0-235.0)	232.8 (184.0-269.0)	204.4 (175.0-237.0)
Ammonia (NH_3), mg·ℓ^{-1}	5	4.27	7.02 (5.19-8.24)	5.98 (4.58-7.63)	6.53 (4.58-7.93)	6.29 (3.05-10.07)	8.94 (7.63-10.68)
Nitrite (NO_2), mg·ℓ^{-1}	5	0.195	0.293 (0.254-0.347)	0.349 (0.330-0.379)	0.119 (0.069-0.159)	0.139 (0.020-0.238)	0.152 (0.026-0.244)
Nitrate (NO_3), mg·ℓ^{-1}	5	9.7	6.6 (3.1-10.1)	11.2 (9.7-12.8)	11.4 (8.8-17.2)	9.08 (7.5-9.7)	8.72 (6.60-10.60)
Orthophosphate (PO_4), mg·ℓ^{-1}	5	14.19	17.74 (12.8-21.1)	38.98 (25.5-54.5)	13.90 (10.0-18.80)	5.54 (3.45-6.75)	13.38 (11.55-15.20)
Alkalinity as $CaCO_3$, mg·ℓ^{-1}	5	42.0	54.4 (43.0-65.0)	49.4 (41.0-56.0)	62.2 (53.0-68.0)	78.2 (56.0-90.0)	63.4 (49.0-80.0)
Ca hardness as $CaCO_3$, mg·ℓ^{-1}	5	57.0	44.0 (35.0-52.0)	74.0 (55.0-92.0)	52.8 (35.0-68.0)	50.8 (43.0-62.0)	60.8 (47.0-54.0)
Mg hardness as $MgCO_3$, mg·ℓ^{-1}	5	5.0	34.8 (29.0-44.0)	22.6 (11.0-28.0)	17.2 (8.0-30.0)	16.0 (7.0-27.0)	23.0 (14.0-32.0)
Total hardness as $CaCO_3$, mg·ℓ^{-1}	5	62.0	78.8 (66.0-91.0)	96.6 (80.0-110.0)	64.0 (53.0-79.0)	66.8 (61.0-76.0)	73.8 (61.0-86.0)
Turbidity FTU	5	8.0	56.6 (43.0-72.0)	83.2 (73.0-120.0)	87.2 (69.0-97.0)	114.0 (83.0-146.0)	75.4 (46.0-108.0)

TABLE 4
CHANGES IN WATER QUALITY CONDITIONS IN THE MUSCOVY DUCKS GROW-OUT PONDS OVER A PERIOD OF SEVEN WEEKS (APRIL-MAY 1996 - CYCLE 4). MEAN VALUES IN EACH CASE FOR FIVE SETS OF PONDS (MIN-MAX VALUES IN BRACKETS)

Analysis	**N**	**Before introduction**	**Consecutive weeks (April - May 1996)**						
			1	**2**	**3**	**4**	**5**	**6**	**7**
Dissolved oxygen, $mg\cdot\ell^{-1}$	5	13.7	10.2 (8.6-11.7)	7.76 (6.2-9.1)	10.2 (7.1-12.2)	12.0 (8.3-15.3)	7.8 (5.3-10.6)	2.8 (1.9-4.3)	2.8 (2.0-4.2)
pH	5	10.30	7.59-8.64	6.96-7.78	7.02-7.33	7.11-8.6	7.11-7.68	6.64-6.88	6.72-6.90
Conductivity $\mu S\cdot cm^{-1}$	5	125.0	121.8 (93.0-142.0)	124.2 (117.0-135.0)	129.8 (113.0-146.0)	133.8 (108.0-158.0)	148.8 (126.0-177.0)	157.2 (133.0-180.0)	173.6 (134.0-185.0)
Ammonia (NH_3), $mg\cdot\ell^{-1}$	5	0.49	0.89 (0.61-1.16)	0.68 (0.49-0.79)	0.66 (0.39-0.89)	1.29 (0.78-1.88)	1.88 (1.34-3.53)	3.14 (2.24-5.00)	4.95 (2.14-7.50)
Nitrite (NO_2), $mg\cdot\ell^{-1}$	5	0.244	0.504 (0.109-0.888)	0.329 (0.125-0.677)	0.543 (0.079-1.535)	0.924 (0.218-2.558)	1.449 (0.462-1.165)	0.900 (0.023-1.551)	0.604 (0.040-2.525)
Nitrate (NO_3), $mg\cdot\ell^{-1}$	5	6.06	6.0 (5.7-6.2)	7.8 (6.6-11.0)	5.9 (3.5-7.9)	7.66 (4.80-10.10)	6.06 (4.8-8.4)	6.86 (4.8-8.8)	5.72 (4.8-7.9)
Orthophosphate (PO_4), $mg\cdot\ell^{-1}$	5	6.81	9.11 (5.50-11.94)	9.11 (8.38-9.91)	9.10 (6.62-11.79)	11.77 (9.23-15.25)	13.48 (10.16-17.48)	13.02 (9.45-16.08)	15.29 (9.55-16.15)
Alkalinity as $CaCO_3$, $mg\cdot\ell^{-1}$	5	27.0	40.4 (29.0-47.0)	39.2 (37.0-43.0)	39.4 (32.0-49.0)	43.2 (37.0-48.0)	46.8 (40.0-49.0)	47.4 (43.0-61.0)	59.4 (42.0-72.0)
Ca hardness as $CaCO_3$, $mg\cdot\ell^{-1}$	5	35.0	41.2 (34.0-48.0)	39.0 (35.0-42.0)	39.6 (37.0-41.0)	38.4 (32.0-43.0)	44.0 (32.0-55.0)	40.6 (33.0-45.0)	46.8 (37.0-63.0)
Mg hardness as $MgCO_3$, $mg\cdot\ell^{-1}$	5	4.0	6.8 (4.0-9.0)	10.2 (7.0-17.0)	9.4 (5.0-15.0)	11.0 (8.0-15.0)	10.8 (7.0-19.0)	12.6 (11.0-15.0)	13.8 (4.0-24.0)
Total hardness as $CaCO_3$, $mg\cdot\ell^{-1}$	5	39.0	48.8 (39.0-57.0)	49.2 (48.0-52.0)	49.0 (44.0-55.0)	49.4 (41.0-57.0)	54.8 (42.0-65.0)	53.2 (45.0-59.0)	60.6 (46.0-68.0)
Turbidity FTU	5	31.0	52.0 (42.0-62.0)	64.2 (43.0-83.0)	49.0 (39.0-58.0)	52.0 (37.0-65.0)	61.8 (48.0-75.0)	90.7 (34.0-115.0)	54.8 (46.0-63.0)

early stages of the different duck production cycles. In the ponds of Cycles 2 and 3, but particularly so in Cycle 2, the ammonia concentrations usually exceeded 5 mg·ℓ^{-1} with peaks exceeding 10 mg·ℓ^{-1} during the last three weeks.

The highest nitrite values were recorded in the ponds of Cycle 4 and fluctuated between 0.329 and 1.449 mg·ℓ^{-1}. In all the other ponds (Cycles 1 to 3) values for nitrite remained relatively lower.

Nitrate concentrations were in all cases relatively high and in some cases exceeded 10 mg·ℓ^{-1} (Cycle 1 - Week 4, Cycle 3 - Weeks 2 and 3).

Concentrations for phosphate remained relatively stable for most of the time in the Cycle 1 ponds with the highest concentrations in Cycle 2 and particularly Cycle 3 ponds (Tables 1 to 3). In the case of the Muscovy duck ponds, there was a definite progressive increase in orthophosphate concentrations between Weeks 4 and 7, with values clearly exceeding 11 mg·ℓ^{-1}.

Alkalinity was variable but reasonably similar during the latter part of all the duck grow-out periods. Highest alkalinity occurred in Cycle 2 and 3 ponds. Values for calcium and total hardness remained relatively constant with highest concentrations for these two determinants occurring in the Cycle 3 duck ponds. Magnesium hardness remained relatively low with highest concentrations for much of the period of investigation occurring in the Cycle 3 ponds (Table 3). Apart from the initial turbidity values of the duck pond water prior to the introduction of ducks, values for this parameter remained variable but relatively similar for all pond systems.

Duck production

The mean individual mass as well as the duck mass range for the consecutive weeks before and on the ponds for the Peking and Muscovy ducks are summarised in Tables 5 and 6. Of all the cycles, the mean mass of the ducks exceeded 3.5 kg at the end of the growth period in Cycle 3. The growth performance of the Muscovy ducks was the poorest with the highest mean mass of 2.291 kg obtained after 72 d. Only in Cycle 1, Peking ducks did not reach a mean mass of more than 3 kg by the end of the 56 d period, but even in this particular case, the mean mass already exceeded the maximum growth obtained for the Muscovy ducks.

Comparing the relative feed conversion ratios (FCR) for the ducks during the four cycles (Table 7), the Muscovy ducks clearly had the poorest performance with an FCR of 4.18. Despite its comparatively poor production performance, the FCR of the Peking ducks in Cycle 1 had an almost identical FCR with those in Cycle 3 with the Cycle 2 ducks sharing the best FCR of all the groups.

Vegetable production

Production results of the four vegetable crops, irrigated with nutrient rich duck pond water over the periods already specified and expressed in kg/1000 m^2 land, are summarised in Table 8. Cabbage clearly produced the highest yields, followed by carrots, spinach and beetroot. The lowest variation in yields for the different plots was reflected by spinach. Cabbage also had the highest variation in yields per plot.

Discussion

The present study is the second of a number of projects which aims at obtaining the necessary know-how on the most efficient application of the concept of the integration of aquaculture with

TABLE 5
THE MEAN INDIVIDUAL MASS $(\bar{X})$ AND RANGE IN KG OF PEKING DUCKS BEFORE AND DURING THE PERIODS THEY WERE KEPT ON PONDS, FOR THREE GROW-OUT CYCLES OF EIGHT TO NINE WEEKS EACH DURING FEBRUARY-MARCH 1996, MAY-JUNE 1996 AND JULY-AUGUST 1996.

Peking duck production cycles														
Cycle 1 (February-March 1996)					Cycle 2 (May-June 1996)					Cycle 3 (July-August 1996)				
Date	Days	N	$\bar{x}$ (kg)	Range (kg)	Date	Days	N	x (kg)	Range (kg)	Date	Days	N	x (kg)	Range (kg)
2/2/96	1	55	0.062	0.061-0.063	6/5/96	5	55	0.082	0.075-0.086	15/6/96	1	55	0.065	0.064-0.068
9/2/96	8	54	0.180	0.172-0.187	13/5/96	12	55	0.376	0.345-0.399	21/6/96	7	55	0.193	0.129-0.198
15/2/96	14	54	0.340	0.317-0.346	20/5/96	19	55	0.963	0.913-1.021	28/6/96	14	55	0.709	0.669-0.741
22/2/96	21	54	0.560	0.527-0.649	27/5/96	26	55	1.505	1.267-1.621	7/7/96	23	55	1.592	1.410-1.841
29/2/96	28	54	0.739	0.638-0.767	3/6/96	33	55	2.109	2.030-2.167	14/7/96	30	55	2.295	2.210-2.395
7/3/96	35	54	1.116	1.002-1.246	10/6/96	40	54	2.606	2.535-2.672	18/7/96	34	55	2.684	2.372-2.813
14/3/96	42	54	1.571	1.450-1.772	17/6/96	47	54	2.912	2.821-3.011	25/7/96	41	54	2.794	2.386-2.994
21/3/96	49	54	2.028	1.863-2.306	24/6/96	54	54	3.225	3.086-3.425	1/8/96	48	54	3.384	2.953-3.444
28/3/96	56	54	2.429	2.261-2.703						9/8/96	56	54	3.650	3.162-3.788

TABLE 6
THE MEAN INDIVIDUAL MASS ($\bar{X}$) AND RANGE IN kg OF MUSCOVY DUCKS BEFORE AND DURING THE PERIODS THAT THEY WERE KEPT ON PONDS FOR A GROW-OUT CYCLE OF 10 WEEKS DURING MARCH - MAY 1996

Muscovy duck production cycle
Cycle 1 (March - May 1996)

Date	Days	N	$\bar{x}$ (kg)	Range (kg)
06/03/96	1	55	0.048	0.044 - 0.053
14/03/96	8	55	0.129	0.123 - 0.133
21/03/96	15	55	0.275	0.243 - 0.304
28/03/96	22	55	0.430	0.412 - 0.467
04/04/96	29	55	0.617	0.526 - 0.683
11/04/96	36	55	0.935	0.875 - 0.984
17/04/96	42	55	1.165	1.037 - 1.263
25/04/96	50	55	1.508	1.424 - 1.595
02/05/96	57	55	1.768	1.648 - 1.889
09/05/96	64	55	2.127	1.944 - 2.314
16/05/96	71	55	2.290	2.013 - 2.548

TABLE 7
PARAMETERS ASSOCIATED WITH THE FEEDING PROGRAMME OF THE PEKING AND MUSCOVY DUCKS DURING A PRODUCTION STUDY DESIGNED FOR FAMILY DUCK-VEGETABLE INTEGRATED AQUACULTURE-AGRICULTURE SYSTEMS

Parameter	Duck production cycles			
	Peking ducks			Muscovy ducks
	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Number of production units	5	5	5	5
Air temp °C mean (min - max)	2/2/96 - 28/3/96 19.6 (7.5-29.7)	6/5/96 - 24/6/96 12.7 (-1.2-28.2)	15/6/96 - 9/8/96 10.6 (-2.0-27.5)	6/3/96 - 16/5/96 16.4 (3.5-29.7)
Water temp °C mean (min - max)	2/2/96 - 28/3/96 22.1 (20.0-24.1)	6/5/96 - 24/6/96 12.3 (10.2-16.1)	15/6/96 - 9/8/96 10.2 (8.1-14.6)	6/3/98 - 16/5/96 18.6 (14.5-24.7)
Feed applied (kg/150 m^2 unit)	461.7	586.4	690.4	462.5
Calculated manure output (dry mass in kg/150 m^2)	37.0	56.8	72.4	47.1
Duck production (kg/150 m^2 unit)	131.2	174.2	197.1	110.7
FCR	3.52	3.37	3.50	4.18

agriculture. Utilising nutrient-rich water discharged from intensive fish production systems, it has been demonstrated that it will be possible to produce at least ten cycles and seven cycles of Peking and Muscovy ducks, respectively, per annum. Based on the present findings, it is possible to produce 1 670 kg of live mass of ducks per 150 m^2 pond space. This amounts to 111 t of Peking ducks or 59 t of Muscovy ducks per ha of pond water. In a previous duck-fish-vegetable project (Prinsloo and Schoonbee, 1987), ten batches of Peking ducks at a density of 2 500 ducks·ha^{-1} of water were raised on fish ponds over a period of 6 months with an average yield of 32.184 t·ha^{-1} and a mean FCR of 3.05. In the present study the production of the Peking ducks (111 t·ha^{-1}) were considerably better even if the results by Prinsloo and Schoonbee (1987) were adjusted to a theoretical 10 cycle duck production period. Even the Muscovy ducks with a yield of 59 t·ha^{-1} performed slightly better than the Peking ducks of Prinsloo and Schoonbee (1987). However the FCR values obtained for the Peking ducks (3.37 to 3.52) and Muscovy ducks (4.18) were less

TABLE 8
PRODUCTION OF SELECTED VEGETABLE CROPS, FLOOD IRRIGATED WITH NUTRIENT ENRICHED WATER FROM DUCK PONDS USED IN THE GROW-OUT OF PEKING AND MUSCOVY DUCKS DURING THE PERIOD MARCH-SEPTEMBER 1996

Vegetables	Number of plots	Vegetable production in kg/1000m^2		
		Mean	Range	Mean yields according to Coertze (1996)
Cabbage (Green cornetto)	15	9120	6505-12408	5 000
Carrots (Cape market)	10	6598	5150-8047	3 000-4 000
Beetroot (Detroit dark red)	10	3790	2788-4792	3 000*
Spinach (Fordhook giant)	10	4974	4765-5184	4 000-6 000

* without foliage

favourable than the findings on the Peking duck growth experiment (FCR 3.05) by Prinsloo and Schoonbee (1987). It was also demonstrated that the reuse of the same water for fish and duck production did not materially affect the health status of the ducks in any way. This is exemplified by an almost 100% survival rate of both duck varieties over the seven to ten weeks of the investigation.

Effluent water from the duck ponds, was also profitably used to produce four different vegetable crops. Based on data provided by Coertze (1996) on the production of cabbage, carrots, beetroot and spinach, yields obtained during the present study with the exception of spinach, outperformed the mean yields given for these crops, showing the beneficial use of the flood irrigation of the fish-cum-duck pond water. A further advantage of the multipurpose utilisation of water from integrated aquaculture-agriculture, is the fact that such water need not be released into and pollute existing streams. However, if this kind of integrated food production system is applied on a wider scale in future, the continued irrigation of such water may have-long term deleterious effects on soil conditions and must be investigated in more detail.

Historically much of South Africa can be considered a low rainfall, semi-arid region. In the rural areas in particular, sufficient quantities of piped water were almost non-existent. Farming was for all practical purposes of a dry-land nature with total dependence on rainfall. In recent years there has been a change in the situation and in future, piped water will increasingly become more accessible to rural communities.

Despite this improvement of available water to all communities, water still remains a scarce natural resource and its most economical use needs to be carefully considered by the consumer. The wider availability of water to the rural communities may provide a new opportunity to combat the existing high levels of malnutrition in certain areas. Water can now be utilised not only to produce vegetable crops but at the same time to produce animal protein in the process of integrating aquaculture with agriculture using the same volume of water. As stated earlier, this concept has been exploited mostly by countries in south-east Asia but can equally be well-established in Southern Africa.

A number of integrated aquaculture-agriculture models can be considered for implementation under local environmental conditions. Ideally fish should be produced with ducks on the same ponds and the pond water, rich in nitrogen and phosphorus used to produce a variety of vegetable crops. To implement this concept the necessary expertise must be available to phase-in such projects.

Acknowledgments

The authors wish to thank the University of the North and Agrelek (Eskom) for facilities provided and financial support which made this investigation possible. Mayford Seeds, Stark Ayers and Kynoch Fertiliser, kindly donated seeds and fertilisers used in this investigation. Our sincere thanks to Prof JE Nel for editorial comments and to Me N Harris for the typing of the manuscript.

References

COERTZE AF (1996) Vegetable information table. Vegetable and Ornamental Plant Institute. Agricultural Research Council. Roodeplaat, Pretoria. 7 pp.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1997) White Paper on a National Water Policy for South Africa. 37 pp.

DIALLO A (1992) Integrated farming: A new approach in the Basse Casamance, Sénégal-Naga. *The ICLARM Quarterly* **15**(3) 21-24.

EDWARDS P and PULLEN RSV (1990) Wastewater fed aquaculture. *Proc. of the Int. Semin. on Wastewater Reclamation and Re-use for Aquaculture*, Calcutta, India, 6-9 December 1988. *ICLARM* No 684. 296 pp.

HOPKINS KD and CRUZ EM (1982) The ICLARM-CLSU Integrated Animal-Fish Farming Project: Final Report. *ICLARM* No 86. 96 pp.

NOBLE RP and COSTA-PIERCE BA (1992) Aquaculture technology research for small holder farmers in rural Malawi. In: *Aquaculture and Schistosomiasis*. National Research Council, Proc. of a Network Meeting held in Mauil, Philippines, 6-10 August 1981. National Academy Press, Washington DC. 169-185.

PRINSLOO JF and SCHOONBEE HJ (1987) Investigations into the feasibility of a duck-fish-vegetable integrated agriculture-aqua-culture system for developing areas in South Africa. *Water SA* **13** (2) 109-118.

PRINSLOO JF, ROETS W, THERON J, HOFFMAN LC and SCHOONBEE HJ (1999a) Changes in some water quality conditions in recycling water using three types of biofiltration systems during the production of the sharptooth catfish *Clarias gariepinus* (Burchell). Part I. Relative efficiency in the breakdown of nitrogenous wastes by the different biofiltration units. *Water SA* **25** (2) 239-252.

PRINSLOO JF, ROETS W, THERON J, HOFFMAN LC and SCHOONBEE HJ (1999b) Changes in some water quality conditions in recycling water using three types of biofiltration systems during the production of the sharptooth catfish *Clarias gariepinus* (Burchell). Part II. Growth and production of sharptooth catfish over a period of seventy eight days. *Water SA* **25** (2) 253-256.

PULLEN RSV and PREIN M (1995) Fishponds facilitate natural resources management on small-scale farms in tropical developing countries. In: Symoens JJ and Micha JC (eds.) *The Management of Integrated Freshwater Agro-Piscicultural Ecosystems in Tropical Areas*. *ICLARM* No **1051** 169-186.

PULLEN RSV and SHEHADEH ZH (1980) Integrated agriculture-aquaculture farming systems. *ICLARM*. 258 pp.

STANDARD METHODS (1995) *Standard Methods for the Examination of Water and Waste Water.* Washington DC.

STEYN NP, NEL JH, PRINSLOO JF, TICHELAAR HY, DHANSAY MA, THERON J, HOFFMAN LC and BENADE AJS (1995) Nutritional status of underweight rural preschool children consuming a diet rich in *Clarias gariepinus. S. Afr. J. Food Sci. Nutr.* **7** (4) 158-163.

TICHELAAR HY, STEYN NP, NEL JH, SMUTS CM, VAN JAARSVELD PJ, PRINSLOO JF, VAN RIJSWIJK AW, DHANSAY MA and BENADE AJS (1995) Fatty acid and nutritional status of undernourished rural Pedi preschool children under 6 years of age in Lebowa. *S. Afr. J. Food Sci. Nutr.* **7** (1) 27-32.